The effect of myelin on the q-space and conventional DTI indices in excised myelin-deficient rat brains

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Introduction

Water diffusion in neuronal tissues was found to be anisotropic more than a decade ago[1] and has been heavily exploited since by diffusion tensor imaging (DTI) to map white matter tracks in the brain.[2] The widely used DTI techniques are based upon the analysis of a single diffusing component although it is well known that at sufficient high diffusion weighting, more than one diffusion component can be observed.[3] High b-value q-space diffusion MRI, emphasizing the slow diffusing component, was used to obtain structural information in neuronal tissues.[4] This methodology was reported to be sensitive to lack of myelin and myelin disorders.[4] Despite of the widespread use of DTI and related techniques, the relative importance of myelin in determining the observed water anisotropy under different experimental conditions is still illusive.[5] In the present study we have used high b-value q-space diffusion MRI and conventional DTI to characterize, for the first time, the diffusion characteristics of myelin deficient (*md*) rat brains[6] and their age-matched controls.[6]

Methods

MRI experiments were performed using a 7T/30cm BioSpec system (Bruker, Germany) equipped with a BGU20 gradient system capable of producing pulse gradients of 40Gcm^{-1} in each of the three dimensions. Formalin-fixed brains of 21-day old *md* (N=4) and control (N=4) rats were used in this study. The MR images were acquired with a field of view (FOV) of 2.56×2.56cm and 256×128 digital resolution reconstructed to 256×256 matrixes, thus affording an in-plane resolution of 100μm. Eight continuous 1mm slices were sampled for each brain. The MRI protocol included high b-values q-space diffusion MR imaging acquired in 6-directions and conventional diffusion tensor imaging (DTI) acquired in 6- and 15-directions. All diffusion experiments were performed using the stimulated echo (STE) diffusion sequence with the following parameters: TR/TE/Δ/δ=1800/20/200/4ms and four averages. The q-space MR images were acquired by incriminating the diffusion gradient from 0 to 30Gcm^{-1} in 16 steps for all 6-directions resulting in a maximal b- and q-values of 18440s/mm^2 and of 511cm^{-1}, respectively. The DTI data sets were acquired with b-max of 2000 s/mm^2.

Results

Fig. 1 shows a partial data set of a representative *md* and an age-matched control rat brain (only one slice out of eight is presented). Figs. 1A and 1B depict the probability and the mean displacement maps, respectively, obtained from the high b-values q-space diffusion MRI experiments. The displacement maps represent the minimum displacement values for the six sampled directions and the probability maps represent the maximum probability for zero displacement of the six diffusion orientation. Figs. 1C and 1D show the FA and λ_3 maps obtained from the DTI protocol (low b-values) with 6-diffusion directions, respectively. Clearly, despite of the fact that the rats were only 21-days old and not fully matured the differences in the white matter (WM) rich areas between the two groups could be observed in all images although to a different extent.

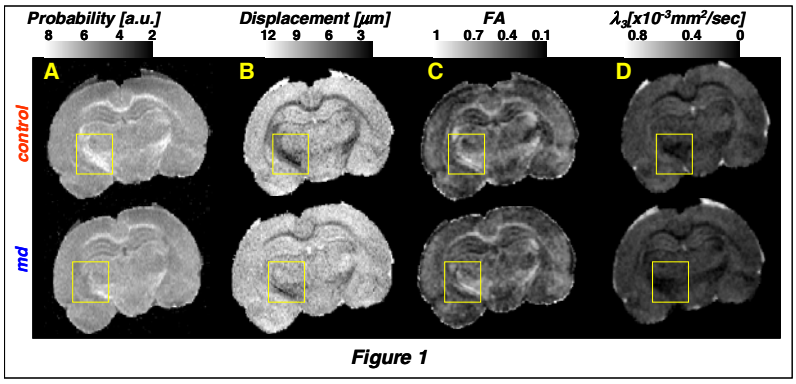

Figure 1

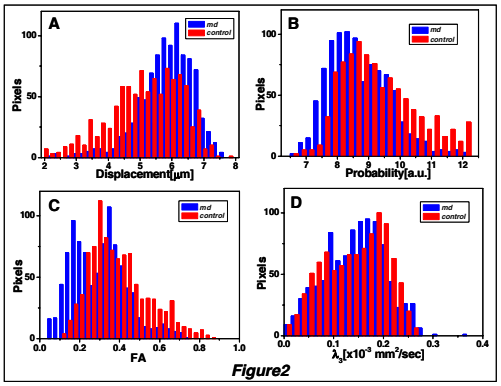

Figure2

Fig. 2 presents a quantitative ROI analysis of WM rich area of some parameters that were analyzed in this study. Figs. 2A and 2B present the probability and displacement histograms obtained from the q-space DWI data set of the two groups, while Figs. 2C and 2D show histograms for the FA and the λ_3 obtained from the DTI data set acquired with 6-directions. This data shows that in the WM of the *md* brains the probability for zero displacement is decreased while the minimal mean displacement is increased like the FA and the λ_3. Interestingly, these histograms also show that the difference between the two groups is the smallest for the λ_3 parameter obtained from conventional DTI.

Discussion

In the early days, myelin was believed to be as the major determinant for the observed diffusion anisotropy in neuronal tissues.[1] However, this hypothesis was challenged by reports by Allen and Beaulieu that demonstrated that nerves lacking myelin show very similar diffusion anisotropy as myelinated nerves,[5] and later by others who showed that anisotropy precedes myelination.[7] This study clearly demonstrates that lack of myelin does affect significantly the diffusion parameters obtained both from DTI and from high b-value q-space DWI. All diffusion parameters studies were found to depend on the myelin content although to a different extent. However, it should be noted that the above diffusion data sets were collected with relatively long diffusion time where the difference in the diffusion anisotropy indices between the two groups are expected to be maximal. The effect of the diffusion time on the different diffusion anisotropy parameters such as the mean displacement, probability, λ_1-λ_3 and FA of the two groups will also be presented.

References

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